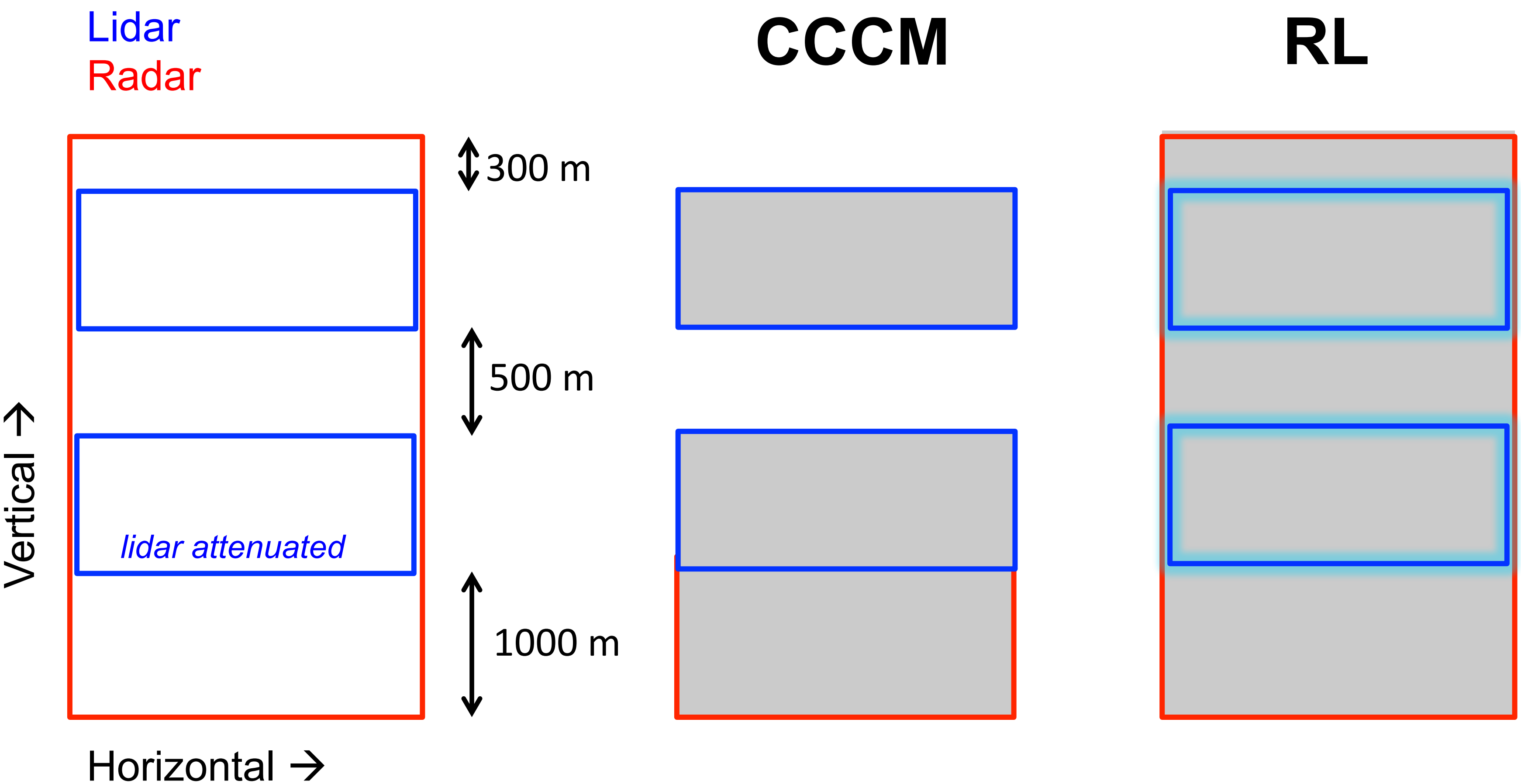
Background & Objectives

- A-train satellite measurements enable us to obtain more accurate cloud profiles from CALIPSO lidar, CloudSat radar, and MODIS imager. CERES group in NASA Langley developed CERES-CALIPSO-CloudSat-MODIS (CCCM) and CloudSat group in CIRA developed radar-lidar (RL) algorithms for combining cloud properties from the active and passive sensors.
- Two algorithms consider different priorities of the sensors and use different filtering method. These cause different cloud properties and their radiative impacts.
- We examine what cause the main differences in these two products, and check feasibility of each method from case studies.
- The problems noted in this comparison can be taken into account in CCCM RelD1 algorithm.

CCCM versus RL Algorithms

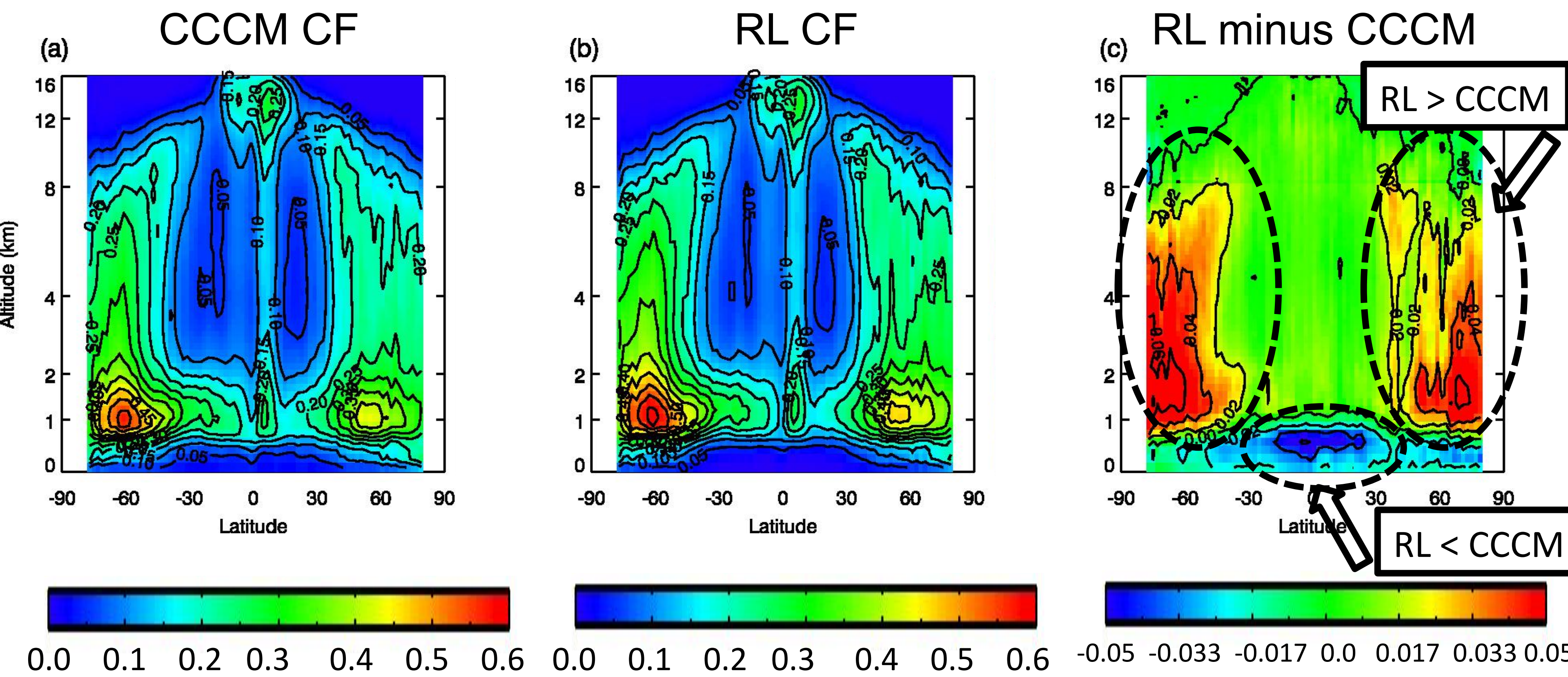
	CCCM (CERES-CALIPSO-CloudSat-MODIS) RelB1	RL (Radar-Lidar) R04 E03 and E04
Distributer	CERES Team/LaRC	CloudSat Team/CIRA
Spatial Resolution	20 km x 20 km of CERES Field-of-View (FOV)	1.4 km x 1.7 km of CloudSat FOV
Vertical Grid Interval	30 m or 60 m of lidar bins	240 m of radar bins
Merging Process of Radar and Lidar Cloud Boundary	▪ Lidar cloud top is firstly used. If radar top is > 480 m higher than lidar cloud top, radar top replaces lidar top. ▪ Lidar base is always used if lidar is not attenuated. If lidar is attenuated and radar sees below, radar cloud base is used.	▪ Lidar is collocated for radar vertical bin, and lidar cloud fraction within each radar bin is computed. ▪ Cloud is detected when radar cloud mask ≥ 20 **OR** lidar cloud fraction (within a radar bin) ≥ 0.5. ▪ Add additional cloud layer is inserted if it is >960 m apart from the existing layers.

Merging Lidar and Radar Cloud Boundary



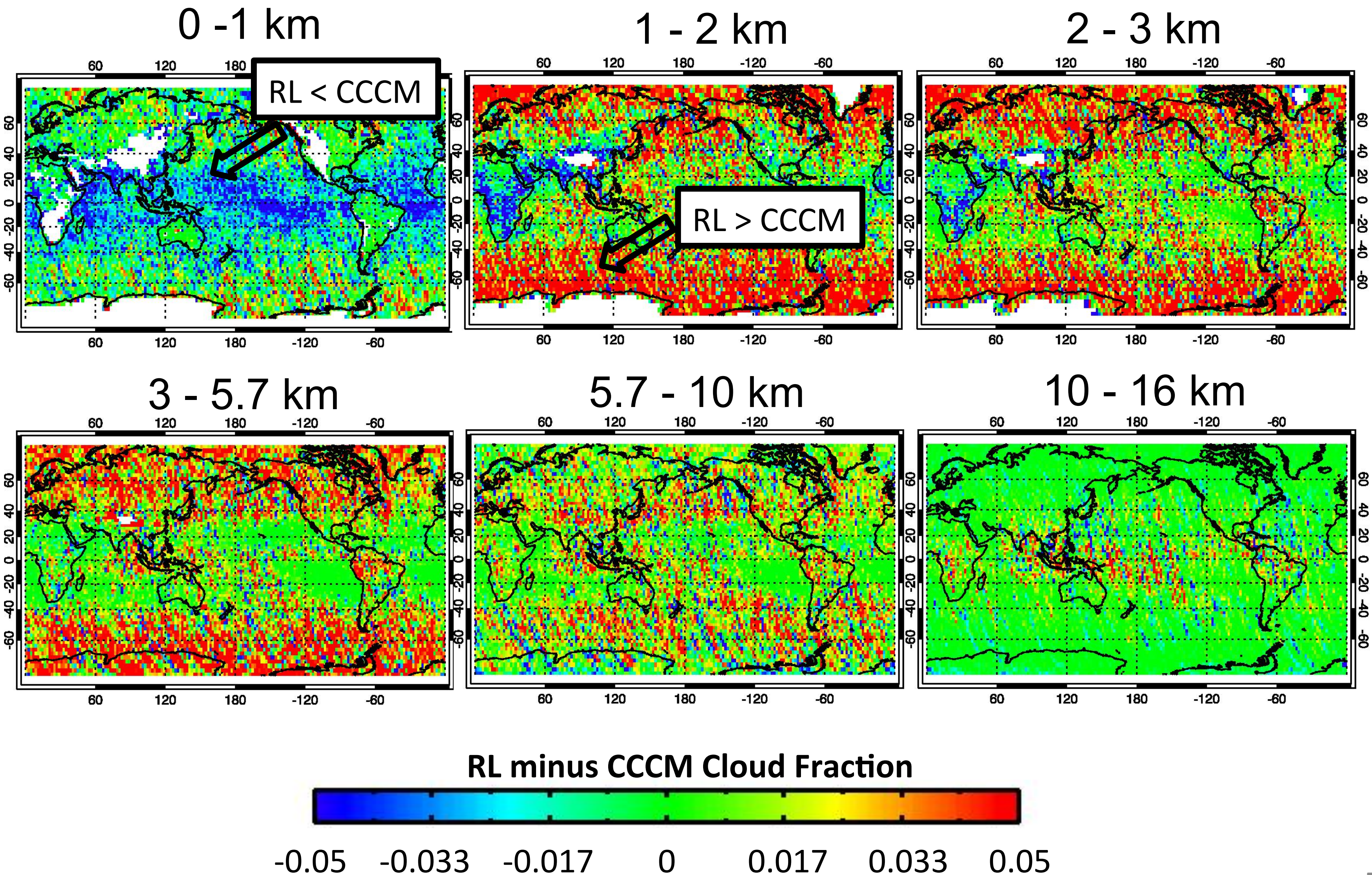
CCCM and RL use the same sensors, but the resultant cloud mask can be different.

CCCM versus RL Cloud Fraction
(Feb Apr Jul Oct 2010 Mean; Ocean/Day)



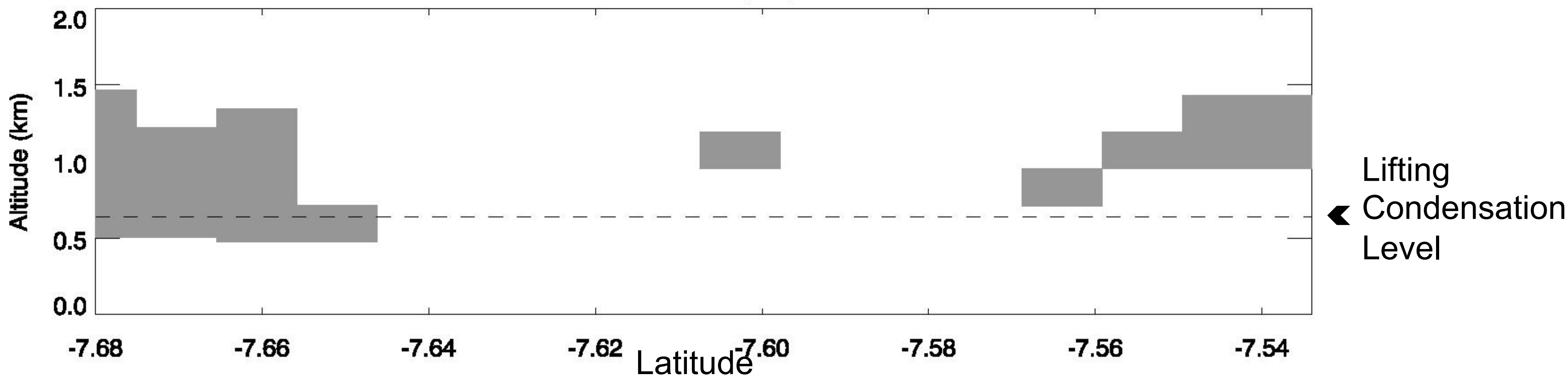
- CCCM CF > RL CF when |lat| > 40°, and 1 km < z < 8 km.
- RL CF < CCCM CF when |lat| < 30° and z < 1 km.
- CF difference is often up to 0.05.

[RL] minus [CCCM] Cloud Layer Fraction

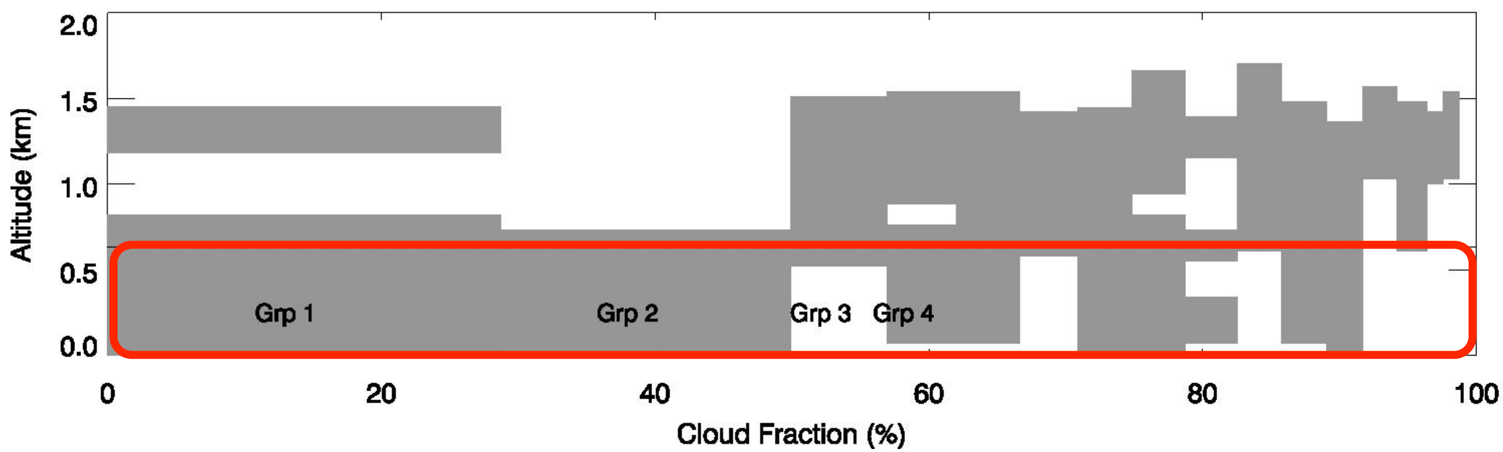


Case 1: Low Clouds in CCCM but Missed in RL

RL Cloud Mask



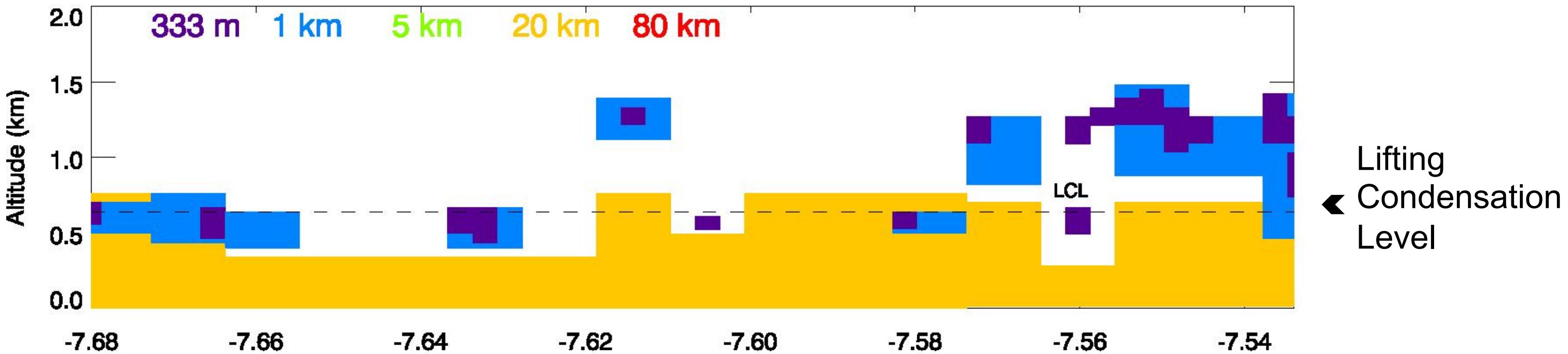
CCCM Cloud Mask



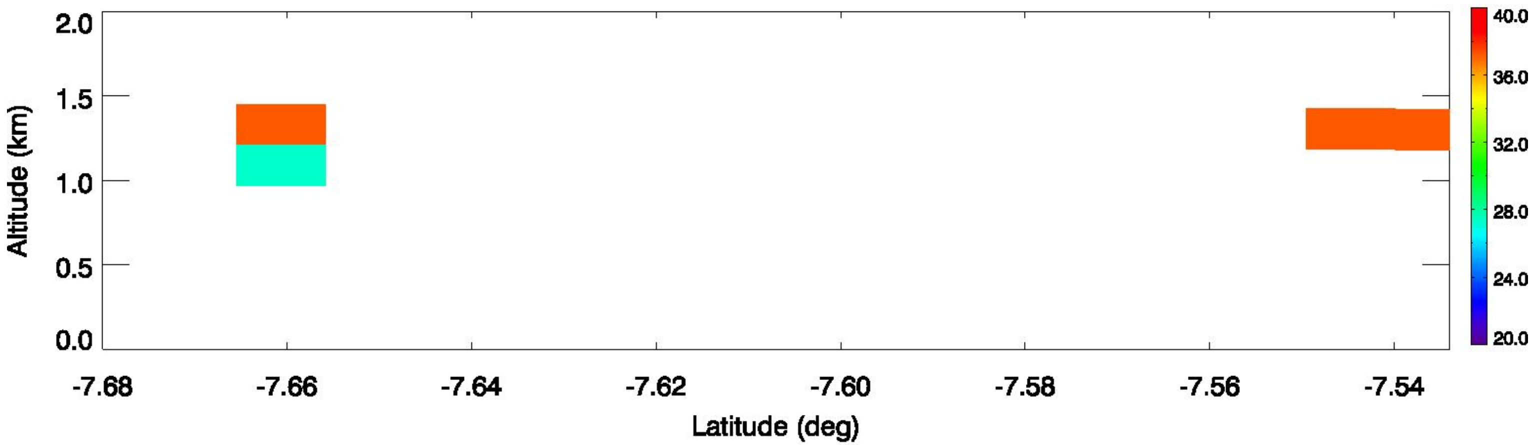
In tropic ocean, CCCM have more low-level clouds (< 1 km) then RL.

Case 1: Low Clouds in CCCM but Missed in RL

Lidar Cloud Mask (Color represents size of space averaging for detection)



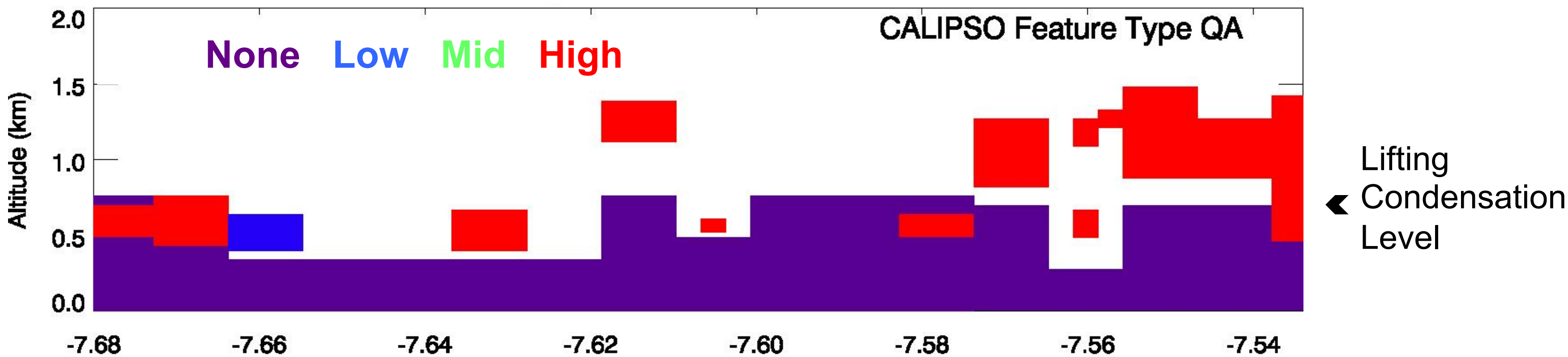
Radar Cloud Mask (≥ 20 is likely cloud; 0 is clear; 40 is overcast)



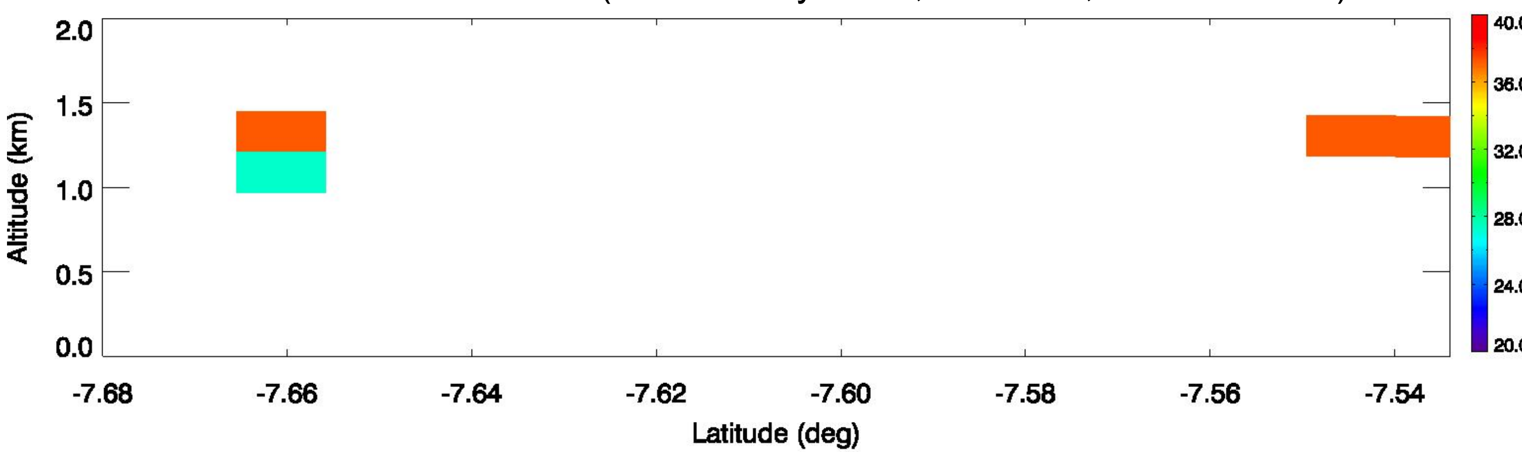
Lidar cloud mask requires horizontal averaging of lidar beams to increase Signal-to-noise. As the optical depth is thinner, larger averaging needed.

Case 1: Low Clouds in CCCM but Missed in RL

Confidence of Lidar Cloud Mask



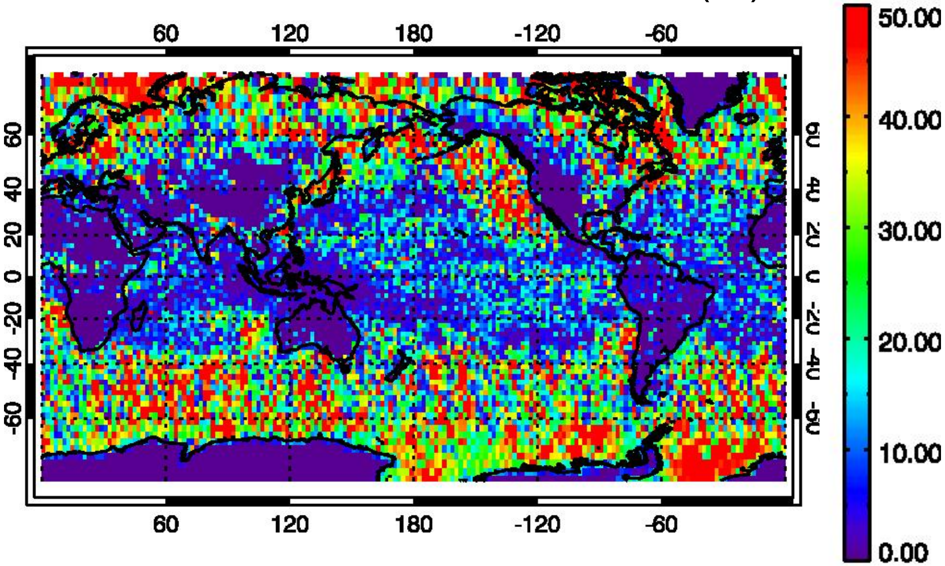
Radar Cloud Mask (≥ 20 is likely cloud; 0 is clear; 40 is overcast)



Confidence is determined by CAD (Cloud Aerosol Discrimination) score. As CAD score is higher, it is more likely cloud.

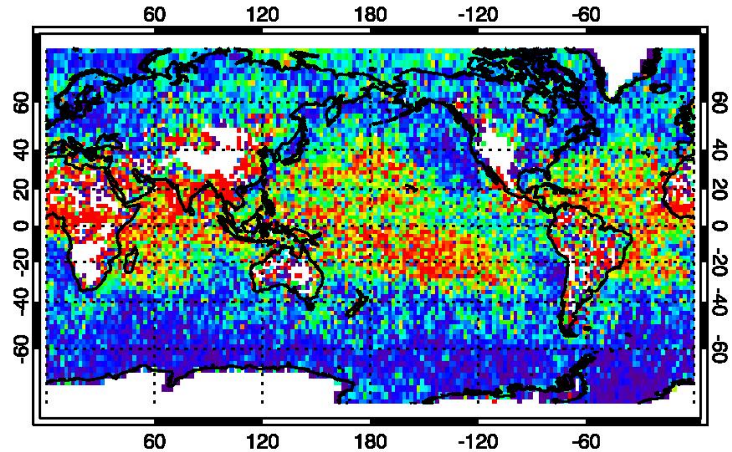
Occurrence of Low-Level (0-1 km) Clouds with Low- and High- Confidence by Lidar (JAN 2011)

Occurrence of Low-Level Clouds (%)

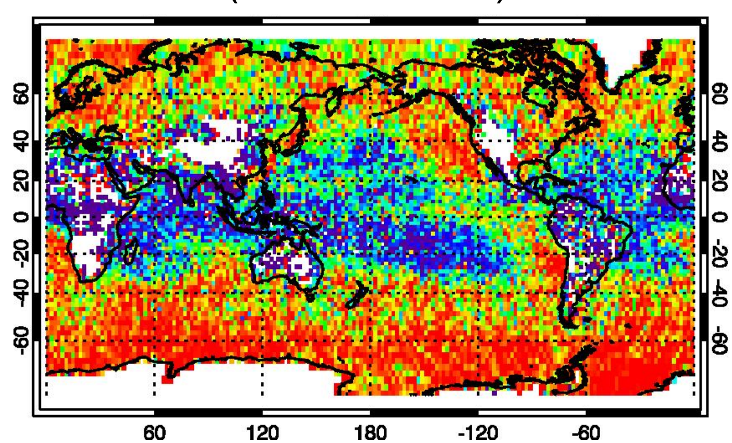


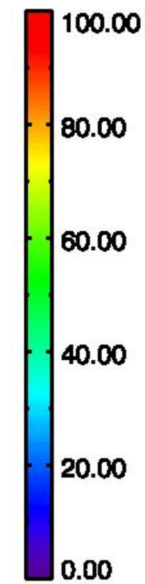
- Low clouds in tropic ocean are detected by Lidar with low confidence.

Portion (%) of Low Confidence
(0≤CAD<70)



Portion (%) of High-Confidence
(70≤CAD≤100)

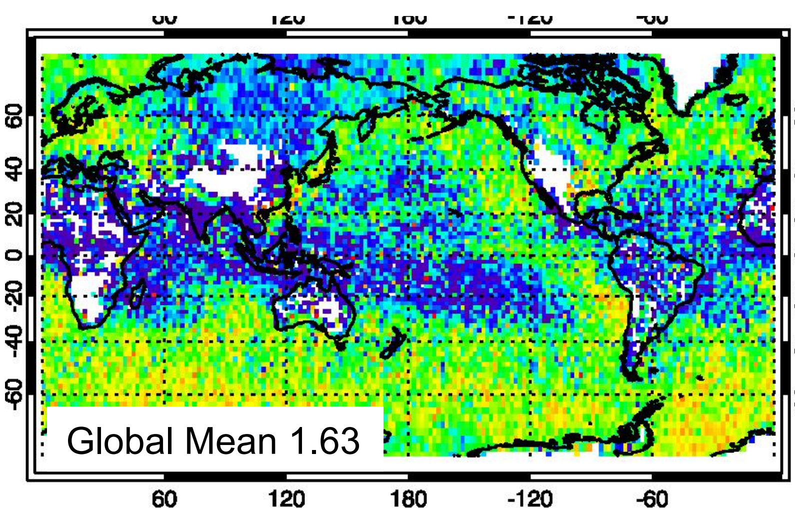




Sum of above two panels is 100% for each pixel.

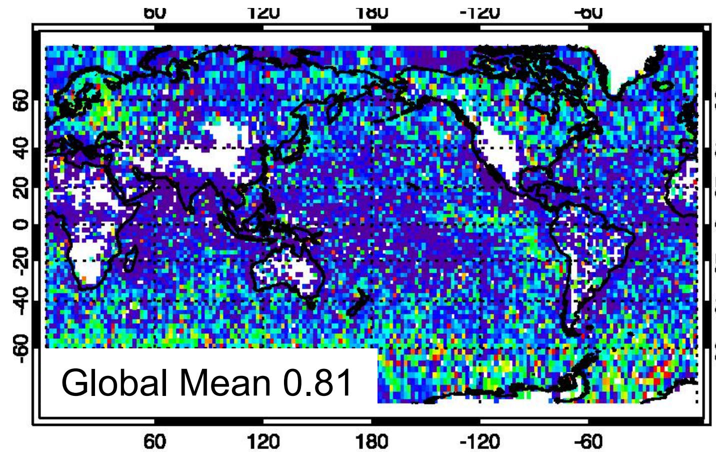
Cloud Optical Depth of Low Clouds with Low- and High- Confidence by Lidar (JAN 2011)

All Low Clouds

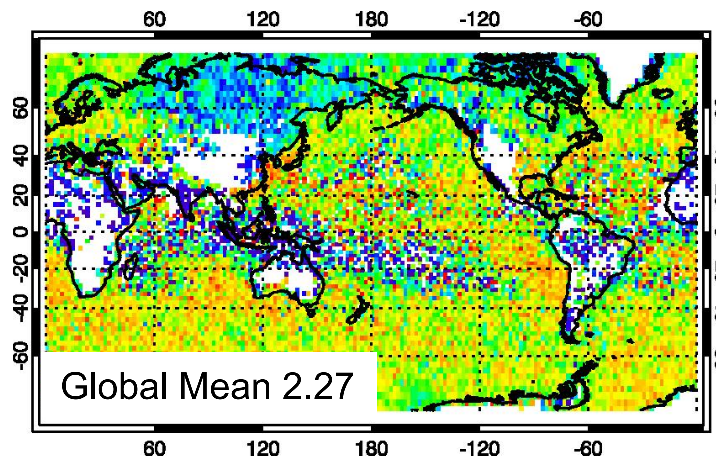


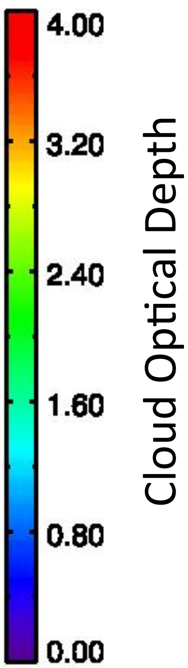
- Optical thickness of tropic marine stratus is smaller than 1.

Low Clouds with Low Confidence



Low Clouds with High Confidence

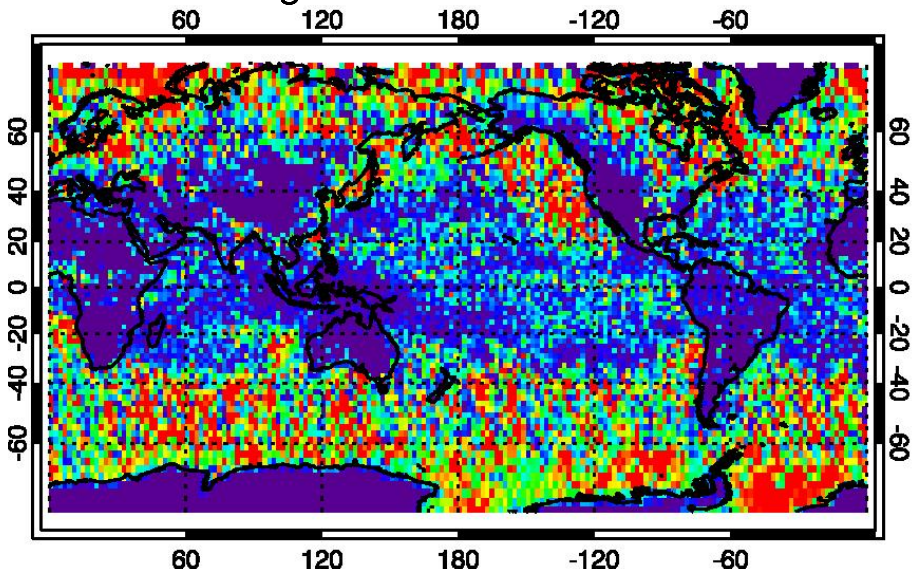




Occurrence of Low-Level Clouds with Low- and High-Confidence by Lidar (JAN 2011)

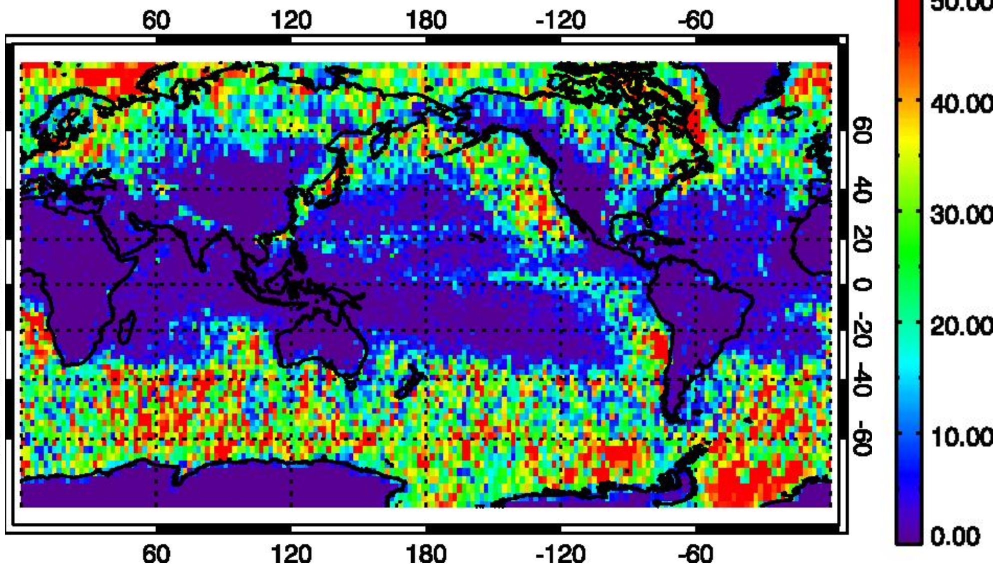
"CCCM-Like"

Low Cloud Occurrence (%)
Regardless of Confidence



"RL-Like"

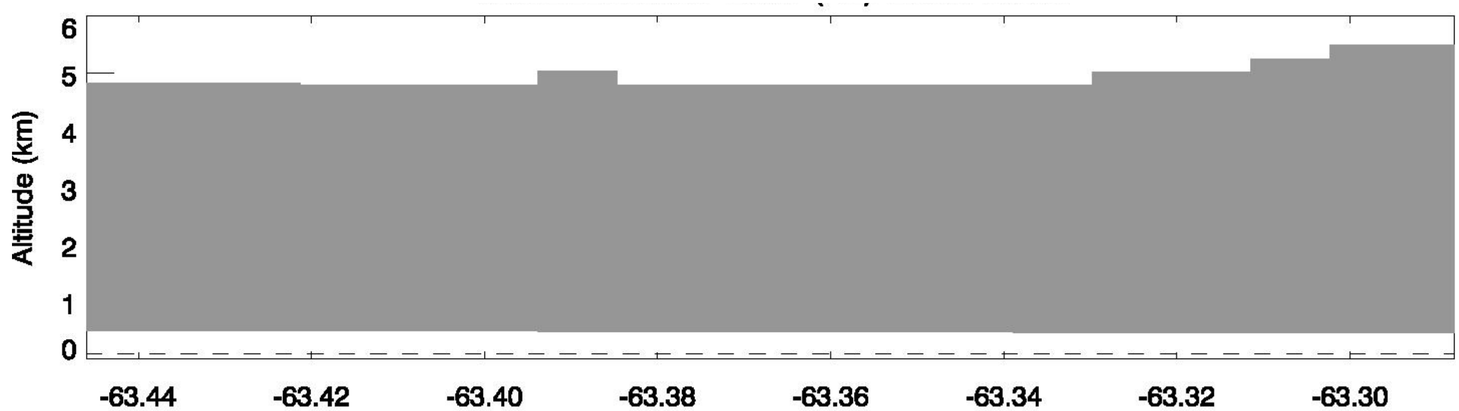
Occurrence (%) of Low Clouds
with High Confidence



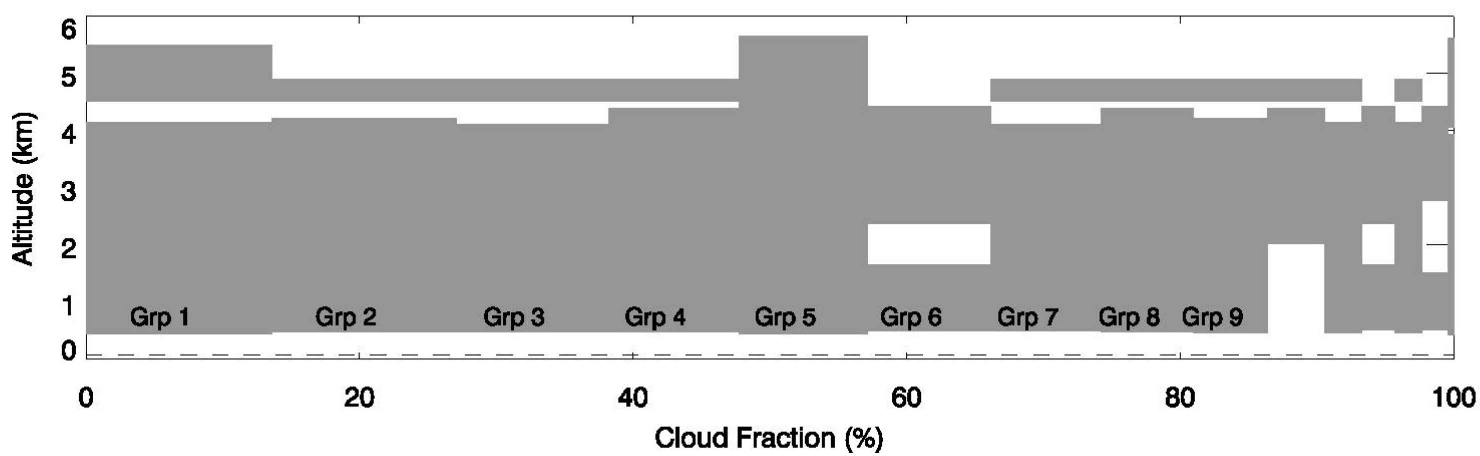
- Low cloud layer < 1km in tropic may be related to aerosol (low CAD score means higher probability of aerosol).
- The low clouds in tropic ocean have optical depth around 0.8 and coverage is very small < 20%.
- The low clouds in tropics are mostly over ocean and far from the west coast.

Case 2: Multilayered Clouds in CCCM but Single layer in RL

RL Cloud Mask



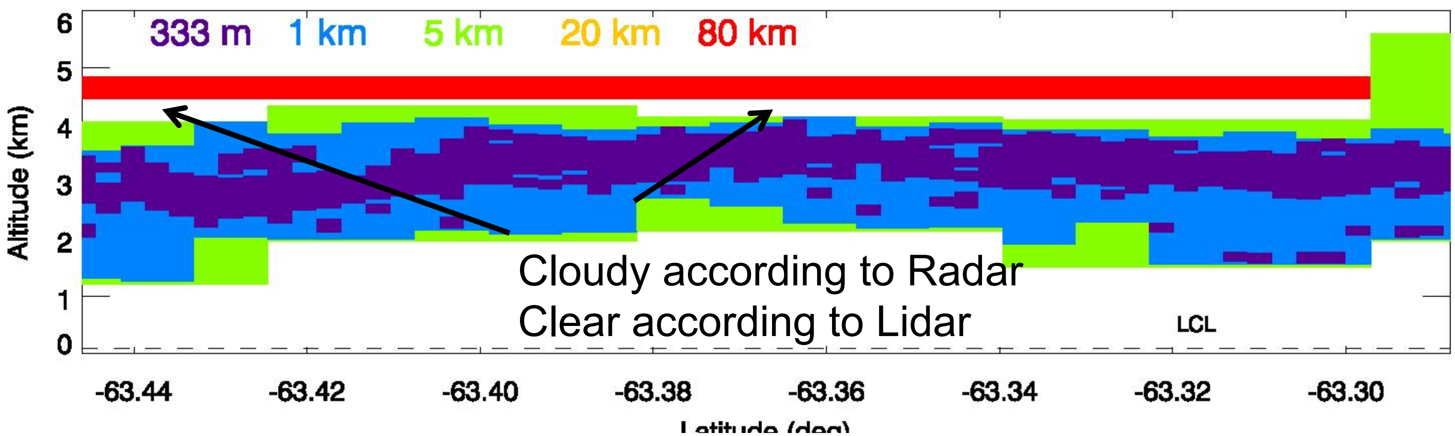
CCCM Cloud Mask



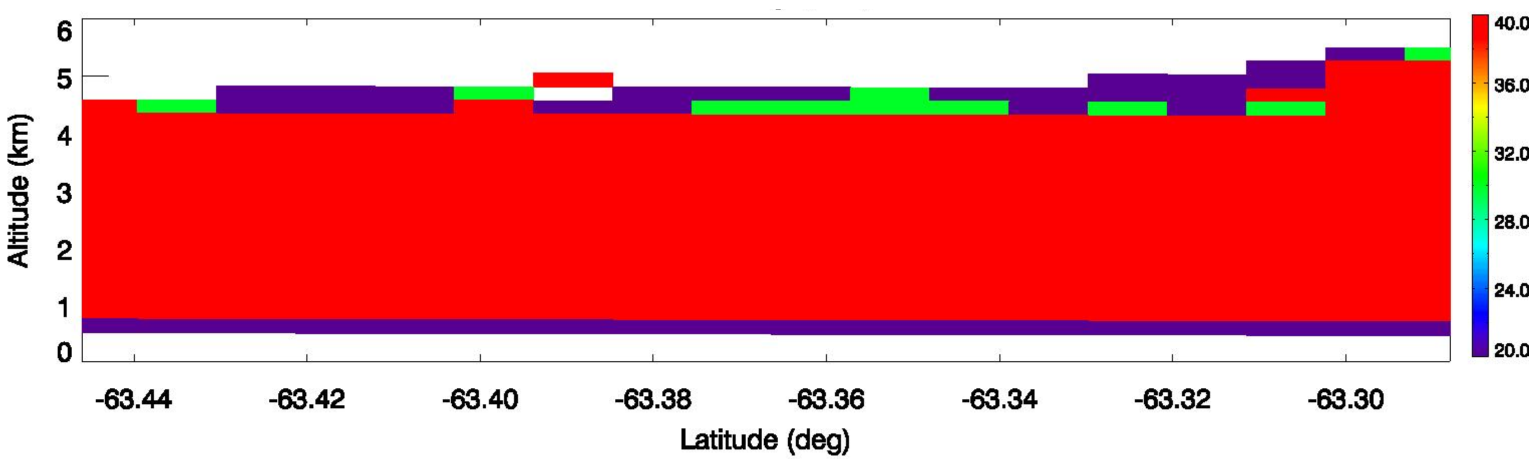
In high-latitude region (> 40 deg), RL has larger cloud fraction than CCCM.

Case 2: Multilayered Clouds in CCCM but Single layer in RL

Lidar Cloud Mask (Color represents size of space averaging for detection)



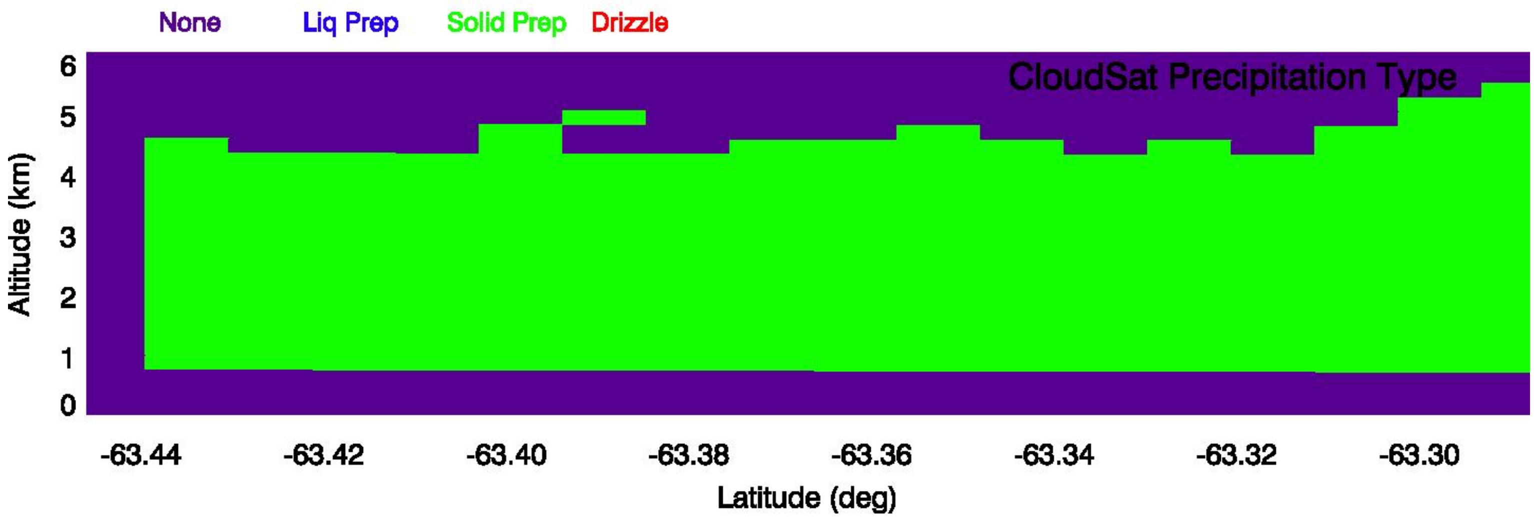
Radar Cloud Mask (≥ 20 is likely cloud; 0 is clear; 40 is overcast)



Lidar has a clear zone between two cloud layers, but Radar only have one single layer.

Case 2: Multilayered Clouds in CCCM but Single layer in RL

CloudSat CLDCLASS Precipitation Flag

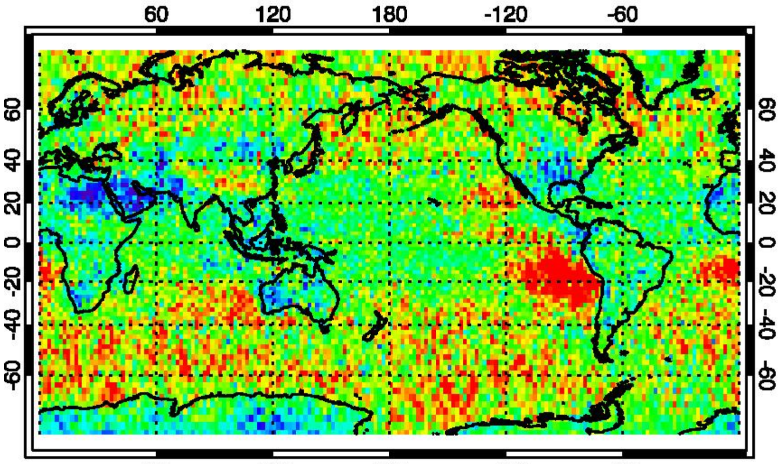


- Clear according to lidar and cloudy according to radar often involves precipitation (more than 50%).
- Radar signal is very sensitive to large particle (~ D^6) than lidar (~ D^2). Therefore, small number of precipitating particles can cause different cloud mask from lidar and radar.

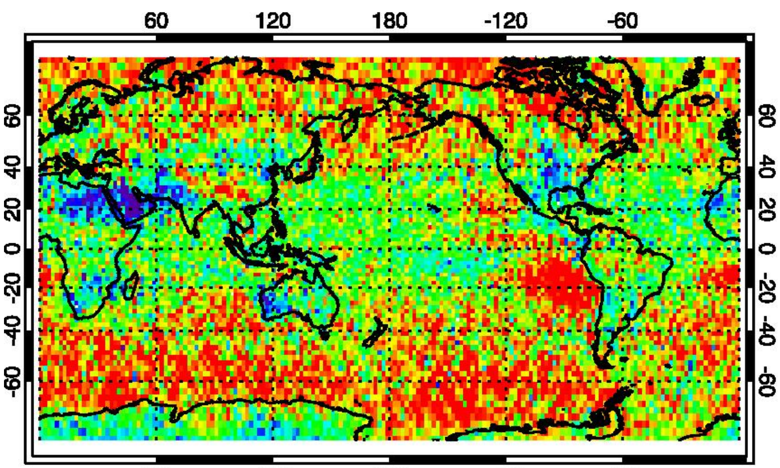
Occurrence of Single/Multi-layer Clouds (Oct 2010)

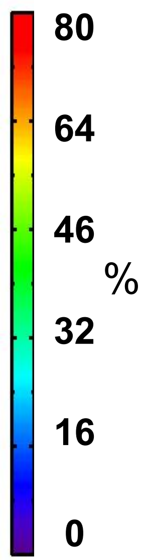
Single Layer

CCCM (47.04%)



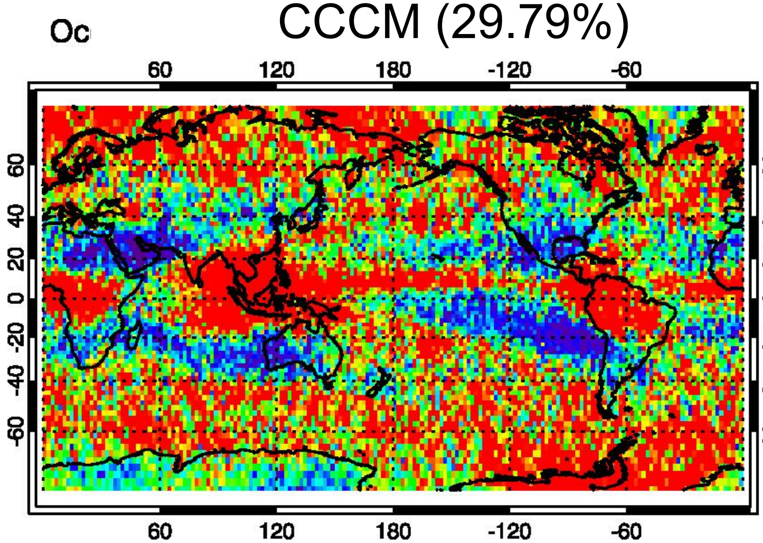
RL (53.03%)



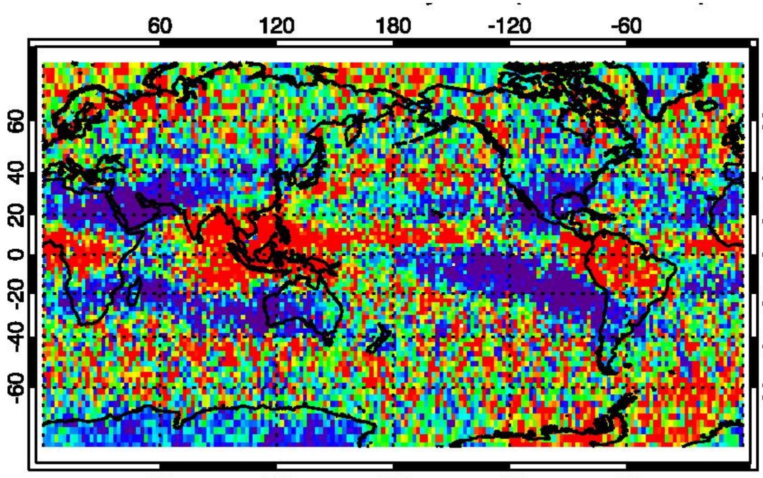


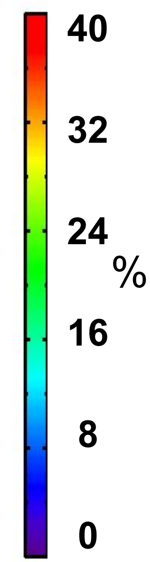
Multi-Layer

CCCM (29.79%)

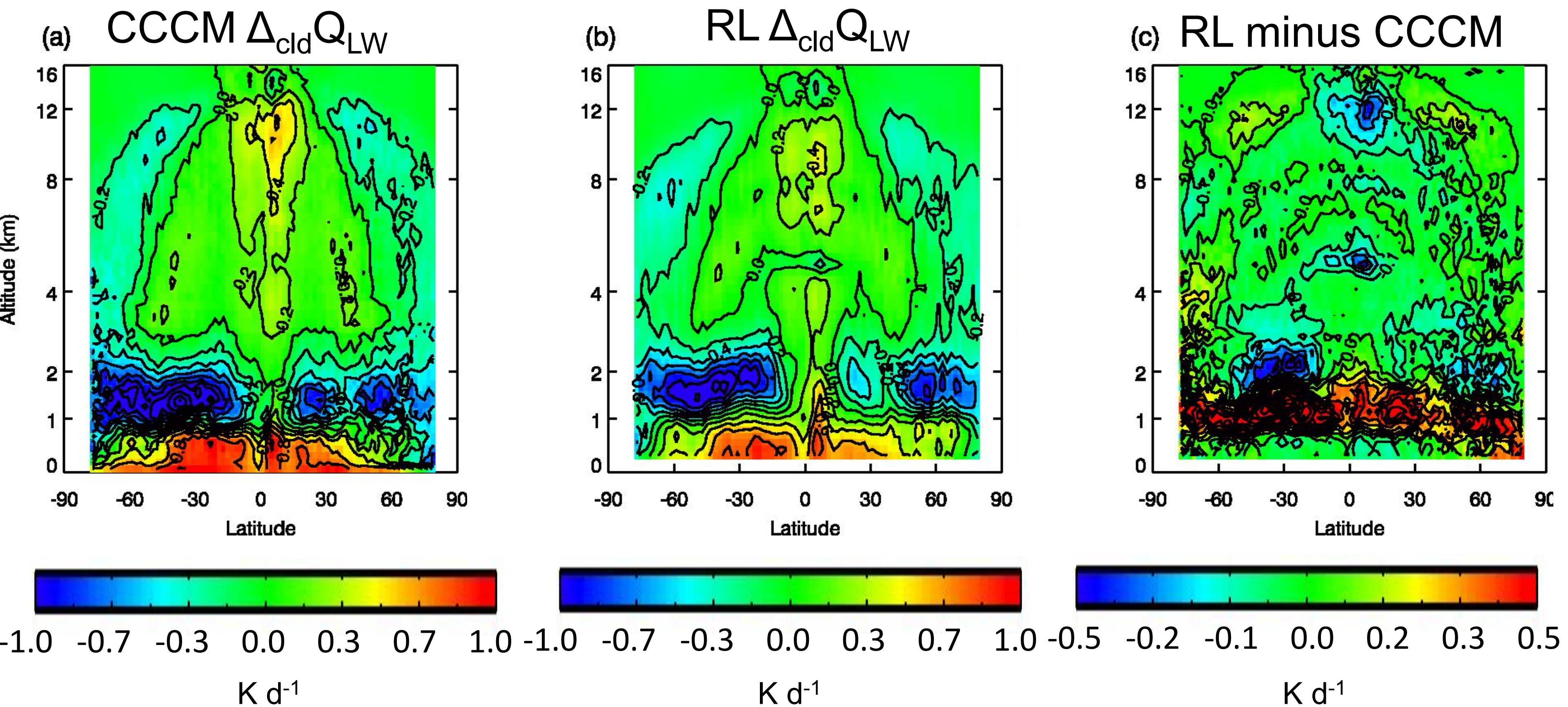


RL (22.13%)





Cloud Radiative Impact on LW Heating Rates (Q_{LW})

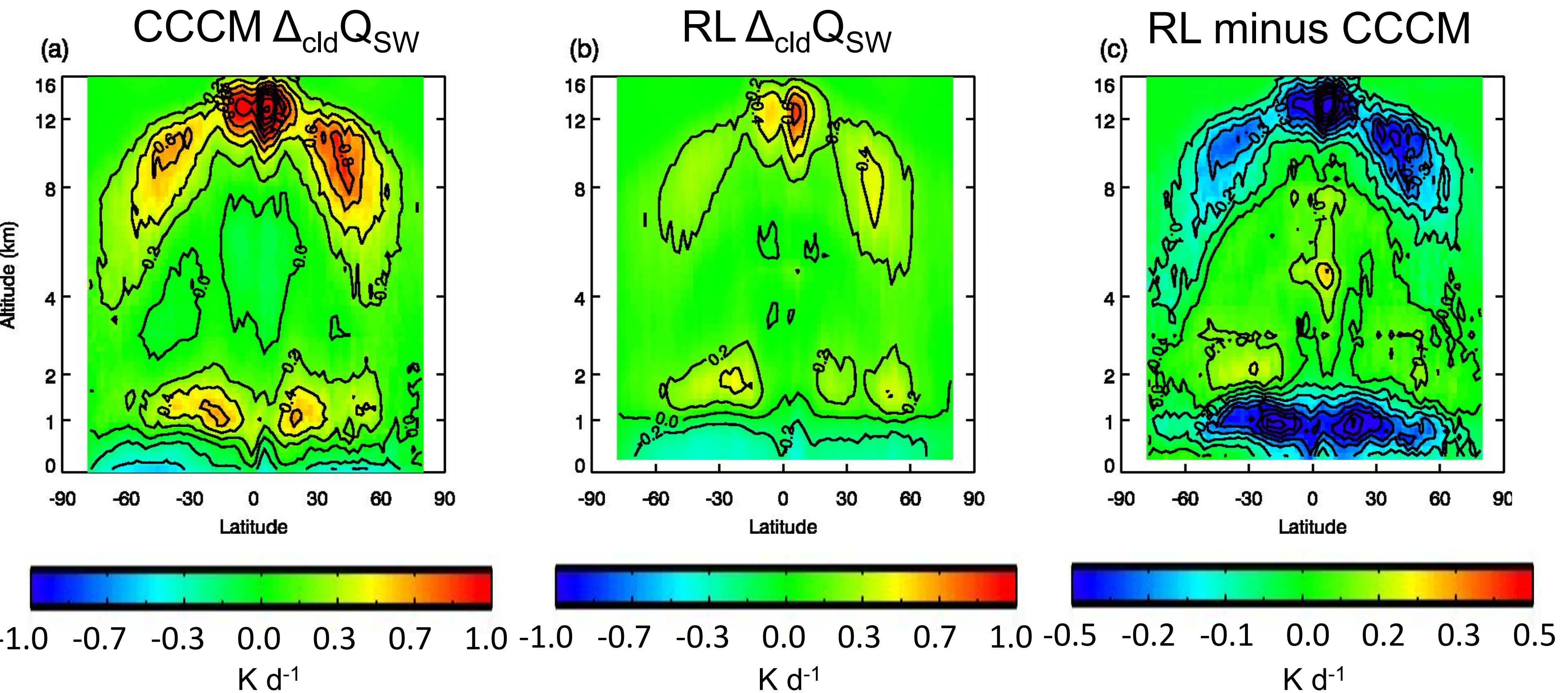


- Cloud produces LW radiative cooling at cloud top and warming within the cloud layer.
- As the cloud top is higher, LW warming is larger.

Summary

- CCCM has more low (< 1 km) clouds in tropics, while RL has more mid-level (1-8 km) clouds in high latitude region.
- Low clouds (< 1km) over tropic ocean often have low-confidence (CAD score). This is included in CCCM but not in RL. This type of layer have small optical depth (~ 0.8) and small coverage according to lidar measurements.
- RL has more single-layered clouds than CCCM (or CCCM has more multilayered clouds than RL in high-latitude region.) This is related to precipitating layer between clouds.
- The differences in low level clouds distribution results in LW heating rate differences between CCCM and RL.

Cloud Radiative Impact on SW Heating Rates (Q_{SW})



- Cloud produces SW radiative heating due to cloud absorption of sunlight.
- As particle increases, cloud absorption increases too.
- RL has smaller SW radiative heating by clouds, implying that particle size is smaller than the one used in CCCM.

Cloud Radiative Effects on Heating Rates

Net flux [W m^{-2}] $F(z) = F_{up}(z) - F_{dn}(z)$

Heating rate Q [K d^{-1}] $Q(z) = -\frac{1}{\rho c_p \Delta z}[F(z + \Delta z / 2) - F(z - \Delta z / 2)]$

CRE on heating rate Q [K d^{-1}] $\Delta_{cld} Q(z) = Q_{all}(z) - Q_{clr}(z)$